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(54) Power control method and apparatus for satellite based telecommunications system

(57) A power control method and apparatus are provided for a satellite based telecommunications system. The system includes a power control subsystem which is operative with systems operations center for distributing available satellite power between earth stations. Each earth station includes a baseband manager which subdivides the available satellite power between subband beams emitted from the satellite. The earth station further includes beam processors which manage the power allocated to each subband within an associated beam in order to maintain a desired signal quality in a forward link between the satellite and user terminals within the associated subbands. The beam processors communicate with modems, each of which is assigned to a particular user terminal. Each modem controls the satellites transmission power in the forward link to the user terminals to maintain a desired signal-to-noise ratio at the user terminal receiver. The signal-to-noise ratio is determined by the corresponding beam processor. The subsystem further provides a dynamic power control loop between user terminals in the forward and return links to maintain a desired signal quality. The subsystem automatically controls the satellite output power level to ensure proper power emission by a satellite in connection with feeder links from multiple earth stations.

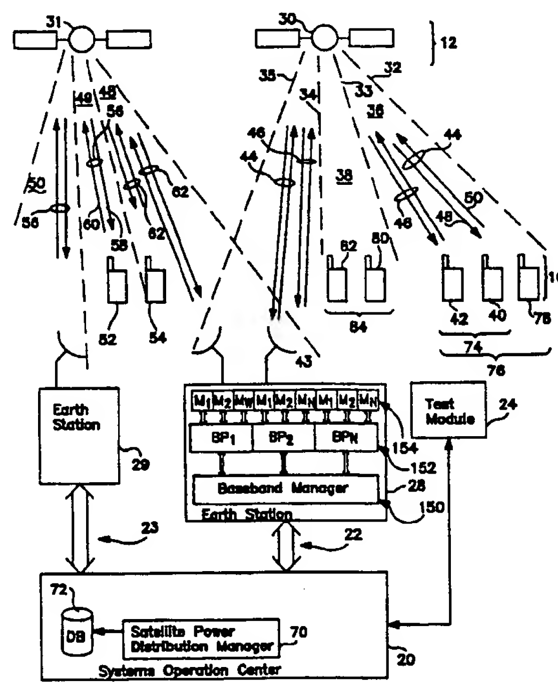

FIG. 1

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OBJECTS OF THE INVENTION

It is an object of the present invention to provide a power control subsystem for a satellite based telecommunications system which optimally allocates power among earth stations with respect to corresponding coverage satellites.

It is a further object of the present invention to ensure that the earth stations, satellites and user terminals operate within federally mandated power flux density limits (PFD limits).

It is a further object of the present invention to provide an adjustable quality of service within forward and return communications links between earth stations and user terminals.

It is a corollary object of the present invention to enable the quality of service to be adjusted based on satellite loading, user position within the satellite's field of view, the forward link signal-to-noise ratio and terminal type.

It is yet a further object of the present invention to ensure that the power control subsystem maintains optimal control when satellite power usage approaches maximum power limits.

It is yet a further object of the present invention to initiate handover operations between beams and/or satellites to optimize satellite power load management.

It is another object of the present invention to provide an aggregate power control subsystem which distributes satellite RF signal power resources between multiple earth stations in such a way that the amplifiers driving the satellite-to-user transmitters are operated at a desired point within a nonlinear operating range to avoid signal distortion.

It is a further object of the present invention to provide a two-way user-level dynamic power control system which adjusts power transmitted to and from an individual user terminal to maintain a desired signal quality at the user terminal and at the earth station.

Another object of the present invention is to provide. automatic level control of the earth station transmission power (EIRP) and receive feeder link power at the satellite.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a block diagram of a satellite based telecommunications system according to the preferred embodiment of the present invention.

Fig. 2A illustrates a block diagram of an earth station of a preferred embodiment of the present invention.

Fig. 2B illustrates a detailed block diagram of the baseband manager and beam processor according to a preferred embodiment of the present invention.

Figs. 3A-3C illustrate the processing sequence followed by the satellite power manager of the preferred embodiment of the present invention.

Fig. 4 illustrates a more detailed block diagram of the beam processor of the preferred embodiment of the present invention.

Figs. 5A and 5B illustrate the processing sequence carried out by the beam processor of Fig. 4 according to the preferred embodiment of the present invention.

Fig. 6 illustrates a forward link power control loop between an earth station and a user terminal according to the preferred embodiment of the present invention.

Fig. 7 illustrates a return link power control loop according to a preferred embodiment of the present invention.

Fig. 8 illustrates an automatic level controller carried out according to the preferred embodiment of the present invention.

Figs. 9A and 9B illustrate exemplary RF signals transmitted in connection with the power level controller of Fig. 8 according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 generally illustrates a satellite based telecommunications system representative of a preferred embodiment. The system includes a plurality of user terminals 10 which communicate with corresponding earth stations 16 via coverage satellites 12. Each user terminal communicates with its assigned earth station via a unique communications channel. A channel includes a forward link from the earth station to the user terminal and a return link from the user terminal to the earth station. Each forward and return link is further divided into an earth station-to-satellite section and a user terminal-to-satellite section. Each channel carries RF signals within a preassigned subband having a central carrier frequency. Each satellite divides its coverage area (e.g., field of view) into multiple beam spots. Each beam spot may support one or more subbands. Thus, the carrier frequency of a particular channel is dependent upon the beam spot covering the user terminal. Fig. 1 illustrates an exemplary implementation of this communications architecture.

As illustrated in Fig. 1, satellite 30 divides its coverage area into three beam spots, the boundaries of which are defined by dashed lines 32-35. Beam spot 36 covers a first group of user terminals, while beam spot 38 covers a second group of user terminals. Terminals 40 and 42 communicate along channels 44 and 46, respectively, with earth station 28. Channel 44 includes a forward link 48 and a return link 50. The satellite 30 relays RF signals along channels 44 and 46 to the earth station 28.

Satellite 31 similarly includes multiple beam spots 48 and 50 which support communications between earth station 29 and user terminal 52. User terminal 52 communicates along channel 56 which includes a forward link 58 and a return link 60. As shown by channel 62, earth station 28 may also communicate with user terminals (i.e., terminal 54) which are covered by satellite 31. Earth station 28 communicates with user termi-

The SOC 20 informs each earth station 28 and 29 of the available satellite power which may be used in connection with user terminals assigned to the earth station. For instance, the SOC 20 may inform earth station 28 that it may distribute 500 watts between the beams/subbands of satellite 30 which are assigned to the earth station 28, and 200 watts among the beams/subbands of satellite 31 which are assigned to earth station 28. Thus, earths station 28 may instruct satellite 30 to transmit up to 500 watts of transmission power within the subbands assigned to earth station 28. Similarly, the earth station 28 may instruct satellite 31 to transit up to 200 watts of power in the beams/subbands assigned to earth station 28. In addition, the SOC 20 may inform each earth station of a maximum power limit which may be transmitted by each satellite per subband per beam spot. This power limit is determined by the SOC 20 in order to ensure that the overall system does not exceed the power flux density regulatory requirements as established by the Federal Communications Commission.

Upon receiving the satellite power allocations and regulatory limits from the SOC 20, each earth station thereafter independently controls the power levels of RF signals transmitted by satellites to each user terminal. As explained below, the baseband managers 150 in the earth stations distribute satellite transmission power among the predicted channels without exceeding the subband regulatory power limits and the satellite's available power assigned to the corresponding earth station.

Throughout operation, each earth station provides power demand feedback information to the SOC 20 which is used to update the power allocation among the earth stations. By way of example, the feedback information may include the total power required of the satellite to maintain communications links with minimum signal quality. In this manner, the SOC 20 monitors the actual and required satellite power usage relative to ideal operating power levels. The SOC 20 periodically updates the satellite power allocations to each earth station based on feedback information from the earth stations concerning loads and required satellite transmitter operating power levels.

Optionally, a mobile link test module 24 may be provided for measuring a satellite transmitter operating level. The test module 24 communicates measurements directed to the SOC 20. Alternatively, or in addition, a telemetry channel may be maintained between the satellite and each associated earth station. When the telemetry channel is used, the satellite may telemeter transmission operating information to the earth station which in turn relays it to the SOC 20. The SOC 20 in turn utilizes the telemetered satellite operating information while updating the power allocations.

Each earth station estimates its current total satellite power usage relative to the allocated power. Each earth station estimates and controls its satellite power usage per subband per beam relative to the regulatory power limits provided by the SOC 20. Each earth station performs user level power control and dynamic fade margin adjustments for each user (as explained below). Periodically, the earth stations report total satellite power usage, along with power usage per subband per beam for each associated satellite.

Turning to Fig. 2A, an earth station 28 is illustrated in more detail. The earth station includes a baseband manager 150, a plurality of beam processors 152, and a plurality of modems 154. Each beam processor operates in connection with an assigned beam emitted by the satellite. Each beam processor includes one or more subband power managers 156 which manage power distribution among the subbands in the associated beam. Each subband power manager 156 communicates with a plurality of modems 154. Each modem 154 operates in connection with a single channel assigned to a particular user terminal. Each subband power manager 156 communicates with all of the modems 154 which support channels in a single corresponding subband. Each modem 154 includes a forward link power controller 160 which controls the power emitted by the satellite within the subband corresponding to the channel assigned to the modem 154. Each modem 154 includes a modulator 162 and a demodulator 164 for modulating and demodulating RF signals transmitted from and received by the earth station in connection with the associated channel. The RF signals emitted by modulators 162 within modems 154 corresponding to a single subband are combined at a summer 166 prior to transmission to form a composite RF signal for the subband. The composite RF signals are transmitted along with a reference tone (explained below).

The baseband manager 150 includes a satellite power manager 158 and beam load manager 161 which operates according to the flow process illustrated in Figs. 3A-3C to control power distribution among beams transmitted by the satellite to user terminals assigned to the earth station.

Fig. 2B illustrates the interconnection between the baseband manager 150 and a beam processor 152 in more detail. The satellite power manager 158 receives the total satellite power allocation for the earth station from the SOC. The satellite power manager 158 also receives the number of expected channels to be assigned to the earth station per beam of the associated satellite. The satellite power manager 158 receives, as feedback, the difference between the required and allocated total power per subband for each beam from the beam processor 152. The satellite power manager 158 communicates with the data base 153 which may store PFD limits downloadable from the SOC. The PFD limits may be accessed by geographic region and carrier frequency which are dependent upon the satellite's current position and the beam of interest. Referring to Fig. 3A, the satellite power manager 158 obtains (step 170) the total available satellite power from the SOC 20. At step 172, the satellite power manager 158 obtains the subband PFD limits and at step

calculation module 157 combines the required SNR value, SNR variance and fade margin to generate a new required SNR value for the forward link (FL) with the current user terminal. This required FL SNR value is supplied to the modem control module 159.

Figs. 5A and 5B illustrate the processing sequence carried out by the subband power manager 156. Initially, modem controller 159 obtains the subband power allocation from the satellite power manager 158 for the current subband (step 200). At step 202, the SNR calculation module 157 calculates the required SNR value as described above. The modem controller 159 outputs the desired SNR value to the modem 154 corresponding to the current channel within the current subband. The modem controller 159 also outputs the power limit which may not be exceeded by the modem. The modem 154 drives the satellite to emit sufficient power in the forward link to establish the desired SNR value at the user terminal. The modem thereafter returns the power level required of the satellite to achieve the desired SNR value. The modem controller 159 receives feedback information from all of the modems corresponding to the current subband and determines the total required power of the current subband to achieve the desired SNR values for each channel within the current subband. The modem controller 159 then determines whether the allocated power for the current subband exceeds or is less than the total power required to achieve the desired SNR values for each active channel within the subband. The modem controller 159 distributes this excess power by determining a desired forward link (FL) SNR value for each user terminal. The desired FL-SNR value represents the SNR level to be maintained by each modem for the forward link of the associated channel. The modem controller 159 calculates the desired SNR level for the current modem based on the associated user terminal's desired FL-SNR value and the excess power available (step 206 in Fig. 5A). The modem controller 159 outputs the desired FL-SNR value and outputs the maximum power level to which the modem may drive the satellite transmitter for the associated channel.

As explained below, each modem 154 continuously adjusts the output power of its associated channel to maintain the desired received SNR value in the presence of beam spot motion and user motion. Thereafter, the modem returns, to the modem controller 159, the forward link satellite output power level emitted in the current channel by the satellite. At step 208, the modem controller 159 combines FL required modem power levels returned from each modem for a subband to determine the total subband power. The modem controller 159 obtains a difference between the required FL subband power and the available FL subband power allotted by the baseband manager and returns a difference power level to the satellite power manager 158 (step 210). The subband power difference represents the difference between the available subband power, as provided by the baseband manager, and the required subband power, as determined by the feedback, from the modems for the current subband.

Turning to Fig. 5B, once the subband power difference is calculated at step 210, flow passes to step 212 at which the controller 157 determines whether the allocated subband power exceeds the required subband power. If so, the excess power is distributed among the modems in a desired manner (step 214). In addition, this excess is reported back to the satellite power manager 158. As explained above, the satellite power manager 158 may decide to take away the excess power from the current subband and allocate it to another subband and/or beam (see Figs. 3A and 3B). If the decision in step 212 is negative, the flow passes to step 216 at which it is determined whether the required subband power exceeds the allocated subband power. If so, the modem controller 159 reduces the desired FL-SNR values for the user terminals within the current subband in order that the output power level associated with the desired FL-SNR values does not exceed the allocated power level.

Optionally, the desired FL-SNR value for each user terminal may be reduced unevenly across the subband such as to maintain the desired FL-SNR value of each user terminal by a proportional amount above the minimum required FL-SNR value for each user terminal. This overpowered condition is reported at step 218 to the satellite power manager 158 which will subsequently, if possible, allocate additional power to the subband in an overpowered state (as explained above in connection with Figs. 3A and 3B). In addition, at step 220, the subband load manager 163 may be instructed to direct new calls to and from user terminals in the same beam to another subband other than the current subband which is operating in an overloaded power state. Thus, the subband load manager 163 distributes new calls among the subbands in order to avoid overloading of a single subband. The subband load manager 163 may operate independently in response to the feedback reported from the subband power manager 156 or alternatively under the direct control of the beam load manager 161 in the baseband manager 150.

At step 192 (Fig. 3B), the beam load manager 161 may determine which subbands within the current beam use the least power to direct the subband load manager 163 to redirect new calls accordingly. The beam load manager 161 then assigns a new channel to this underpowered subband and relays the channel assignment to the subband load manager 163. The subband load manager 163 then uses this assignment information to establish a new channel with the new user terminal.

Optionally, at step 222, a handover processor 165 within the subband load manager 163 may be activated to handover one or more active channels from the current subband to a different subband within the same beam spot. By handing over channels between subbands in this matter, the handover processor 165 shifts load between subbands. The handover processor 165 may be controlled by the subband power manager 156

value is compared with the desired SNR value, and the difference therebetween is used to determine a new power setting command to be passed to the user terminal 10. The new power setting command identifies the power level at which the transmitter 8 must emit RF signals along return link RL to ensure that the satellite receives such RF signals with sufficient quality. The power setting commands are combined with an outgoing traffic signal within a multiplexor 7 and passed to the transmitter 11. The transmitter outputs the RF signal containing the power setting commands along the forward link FL to the terminal 10. A demultiplexor 3 separates the power level commands from the traffic signal and passes the power level commands to the transmitter 8. The transmitter 8 updates its output power based on the received level command. According to the foregoing loop, the return link power is maintained at a desired level.

With reference to Fig. 8, next the discussion turns to the process used to automatically control the power output levels of the satellite transmitter in forward links to all of the associated user terminals. Fig. 8 illustrates a satellite 300 which receives RF signals transmitted by earth stations 302-306 along forward feeder links 308-312. Each earth station 302-306 includes a baseband subsystem 314 which communicates with an antenna subsystem 316. The baseband subsystem 314 includes a multiplexor 318 which receives RF signals containing communications data, command information and the like along traffic channels 320 for all of the user terminals assigned to the earth station 302. The multiplexor 318 combines the RF signals along traffic channels 320 with a reference tone produced by tone generator 322. The communications signals and reference tone are passed along line 324 to the antenna subsystem through an automatic gain controller 326.

The automatic gain controller 326 is controlled to adjust the aggregate output power transmitted by antenna 328 along the feeder link 308. The RF signal transmitted along forward link 308 is received at a feeder link 330 and passed to an automatic gain controller 332. The gain of the automatic gain controller (AGC) 332 is adjusted to force the level of the reference tone embedded in the RF signal to achieve a desired level of the AGC output. By adjusting the gain at AGC 332, the reference tones from each of the multiple feeder links are driven to the same power levels while maintains the relationships between individual user power and the reference tone. In this way, any differences in propagation loss between the multiple feeder links have been compensated prior to combining the RF signals. The 3-way combiner 336 combines the RF signals received at feeder links 330, 338 and 340, respectively, and outputs same from the antenna 342 which defines the coverage region of the satellite. Next, an example is illustrated in connection with Figs. 9A and 9B to explain the manner in which the preferred embodiment achieves automatic level control.

Fig. 9A illustrates an exemplary RF signal 350 produced by the multiplexor 318. The RF signal 350 includes communications data for multiple subbands 352, 354 and 356. The composite signal 350 also includes a tone 358 produced by tone generator 322. The reference tone 358 has an amplitude corresponding to a predefined power output level. For instance, the tone 358 may correspond to two watts of transmission power ultimately transmitted by the satellite 300. The composite RF signal 350 is passed through the antenna subsystem 316 and transmitted from antenna 328.

During transmission, the RF signal may pass through interference, such as clouds, rain and the like. Such interference may alter the magnitudes of the signals within each subband 352-356 and the magnitude of the reference tone 358. The received composite signal 360 in Fig. 9A is representative of the signal received at feeder link 330. The received composite signal 360 includes subband signals 352-356 and a reference tone 358. The magnitudes of the subband signals and reference tone have increased, although, the relative amplitudes between the subband signals 352-356 and the reference tone 358 have not changed. The filter 334 adjusts the gain of the AGC 332 until it outputs the received reference tone 368 at an amplitude corresponding to the predefined amplitude associated with the predetermined output power level (e.g., two watts). Thereafter, the AGC 332 is controlled to output the adjusted composite RF signal 370 (Fig. 9A). As adjusted by the AGC 332, the RF signal 370 includes a referenced tone 378 equal in magnitude to the original reference tone 358 output by the multiplexor 318. In addition, the amplitudes of the RF signals in subbands 372-376 equal the amplitudes of the original subband signals 352-356.

Accordingly, by combining reference tones preassigned to a corresponding transmission power level, the earth station is able to ensure that the satellite receives over the feeder link a composite RF signal having a desired relation between the tone and traffic signals transmitted from the earth station. The subsequent signal transmitted from antenna 342 corresponds in amplitude to the amplitudes established by the relation between subband signals 372-376 and reference tone 378. Accordingly, by adjusting the amplitude of the subband signals 352-356 at the modems relative to the reference tone 358, the earth station is able to control the transmission power generated within each subband at the antenna 342.

Fig. 9B further illustrates a second example of the automatic level control process according to the preferred embodiment of the present invention. Fig. 9B illustrates an original composite RF signal 380, a received composite RF signal 390, and an adjusted composite RF signal 400. The original and adjusted composite signals 380 and 400 include subband signals 382-384 and 402-404, which are equal in amplitude. Reference tones 386 and 406 are also equal in amplitude. This amplitude relationship is maintained even though the received composite RF signal 390 included

user terminal type and user terminal position within a field of view of a satellite.

6. A subsystem according to claim 1, wherein said beam processor determines fade margins based on signal-to-noise ratio information reported to said beam processor from a modem corresponding to a current user terminal.

7. A subsystem according to claim 1, wherein said baseband manager reallocates power between first and second subbands to shift power to said first subband which requires additional power and to shift power from said second subband which includes excess power.

8. A subsystem according to claim 1, wherein said beam processor decreases a desired signal-to-noise ratio for a corresponding subband when a corresponding modem indicates that sufficient power has not been allocated to said subband to achieve said desired signal-to-nose ratio.

9. A subsystem according to claim 1, wherein said beam processor reports a subband power demand for each subband to the baseband manager.

10. A subsystem according to claim 1, wherein said operations center divides a total power capacity of a common satellite between earth stations using beams of the common satellite.

11. A subsystem according to claim 1, wherein said operations center provides to said earth station power limits per subband per beam.

12. A subsystem according to claim 1, wherein said operations center reallocates a total power capacity of a common satellite between earth stations using beams of the common satellite based on feedback power requirement information from said earth stations.

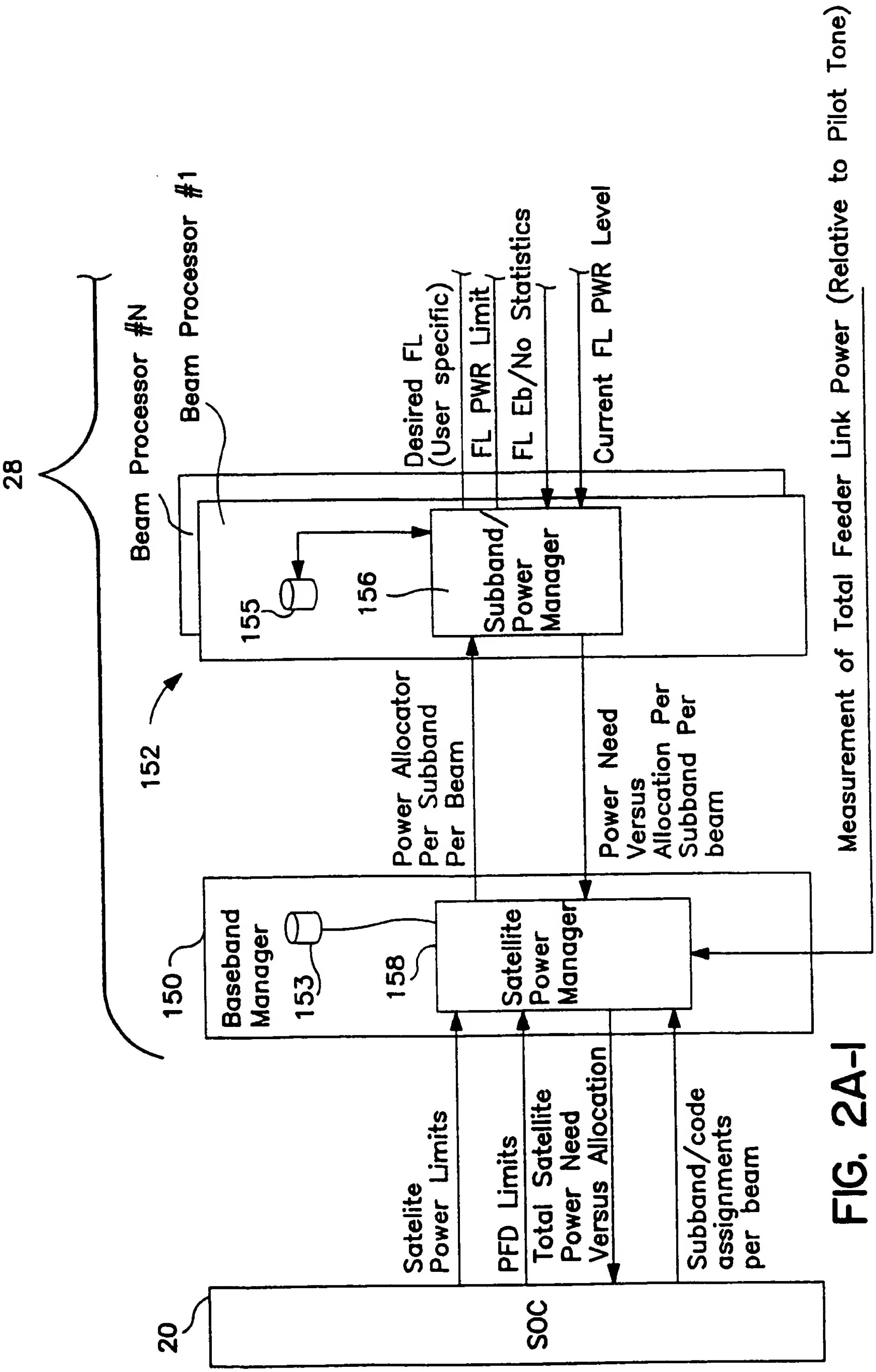
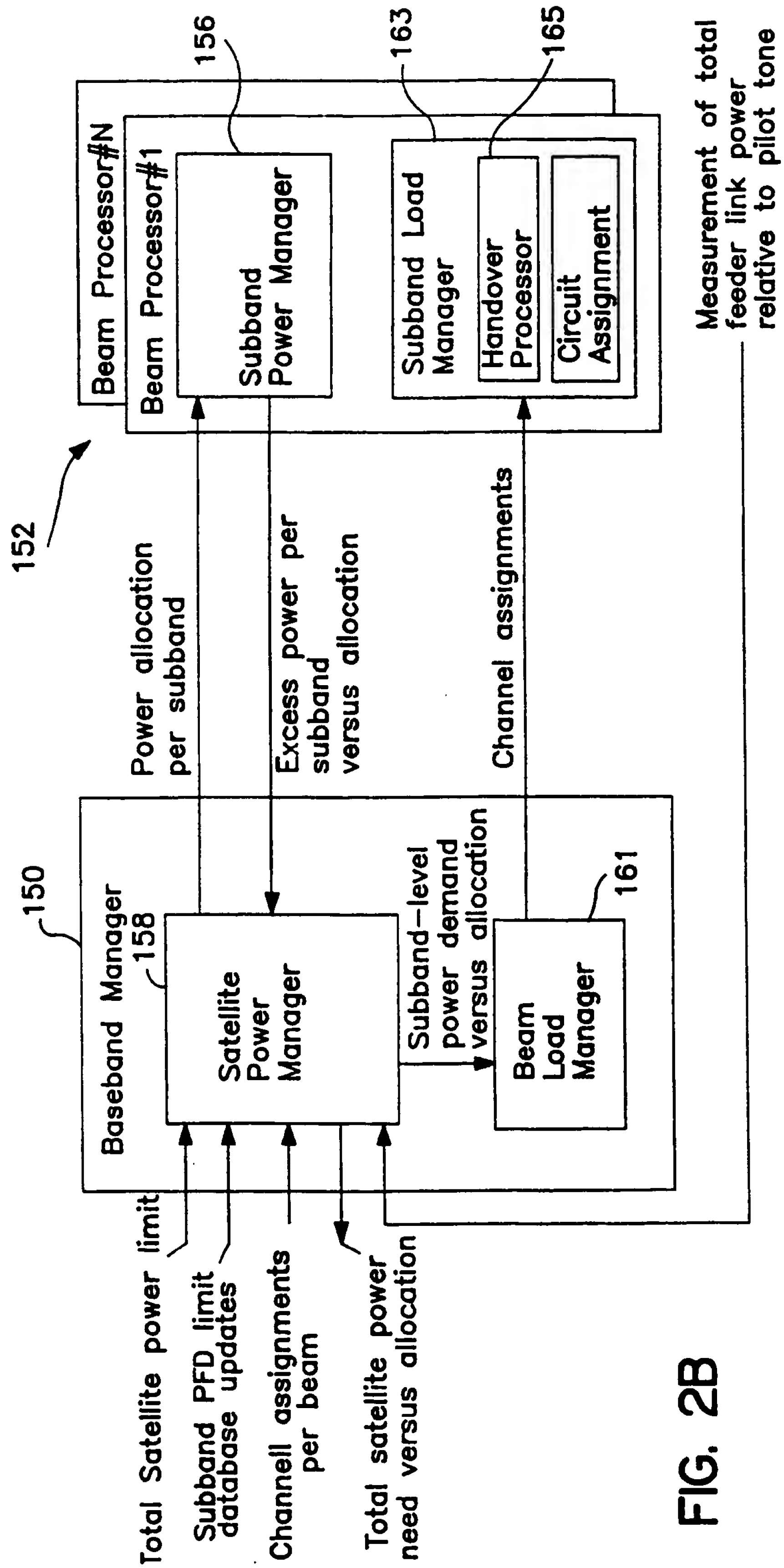

28
Beam Processor #N
Beam Processor #1
Desired FL (User specific)
FL PWR Limit
FL Eb/No Statistics
Current FL PWR Level
Measurement of Total Feeder Link Power (Relative to Pilot Tone)
155
156
Subband/ Power Manager
152
Power Allocator Per Subband Per Beam
Power Need Versus Allocation Per Subband Per beam
150
Baseband Manager
153
158
Satellite Power Manager
Satelite Power Limits
PFD Limits
Total Satellite Power Need Versus Allocation
Subband/code assignments per beam
20
SOC

FIG. 2A-I



Beam Processor#N
Beam Processor#1
156
Subband Power Manager
163
165
Subband Load Manager
Handover Processor
Circuit Assignment
Measurement of total feeder link power relative to pilot tone
152
Power allocation per subband
Excess power per subband versus allocation
Channel assignments
150
Baseband Manager
158
Satellite Power Manager
Subband-level power demand versus allocation
161
Beam Load Manager
Total Satellite power limit
Subband PFD limit database updates
Channell assignments per beam
Total satellite power need versus allocation

FIG. 2B

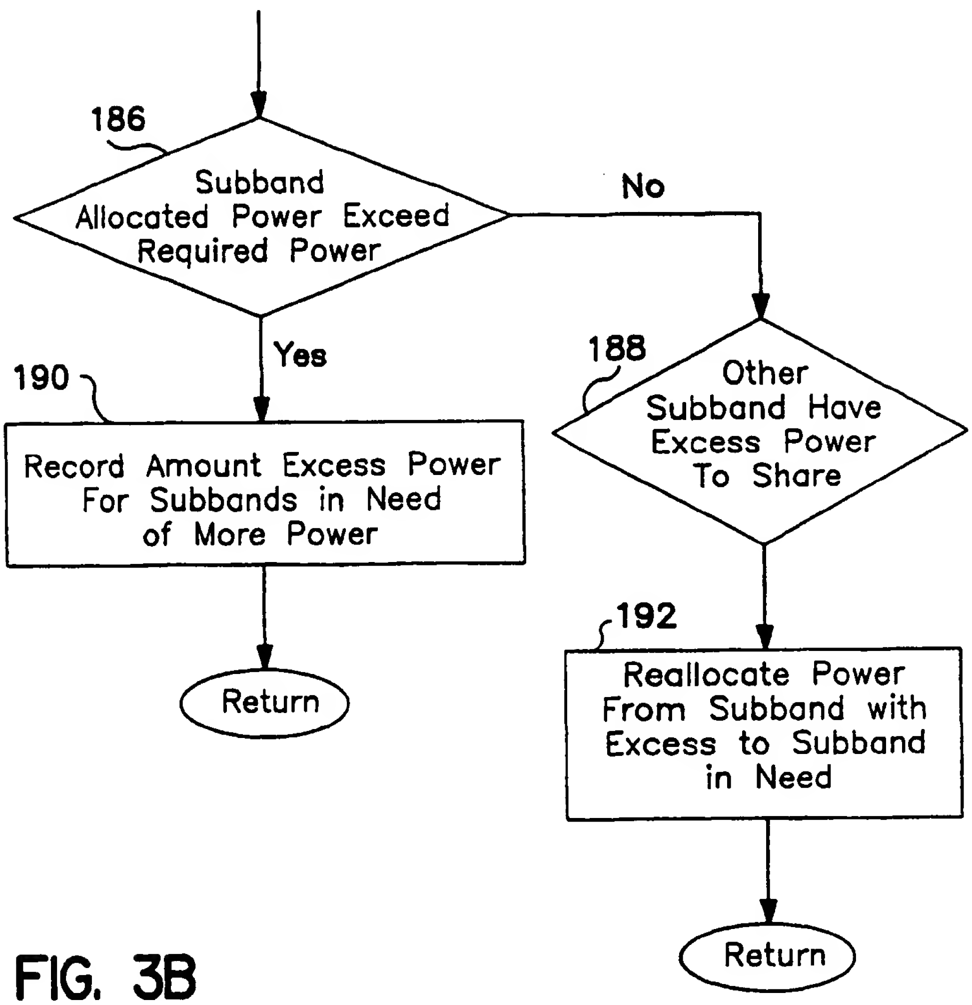

186
Subband Allocated Power Exceed Required Power
No
Yes
190
Record Amount Excess Power For Subbands in Need of More Power
Return
188
Other Subband Have Excess Power To Share
192
Reallocate Power From Subband with Excess to Subband in Need
Return

FIG. 3B

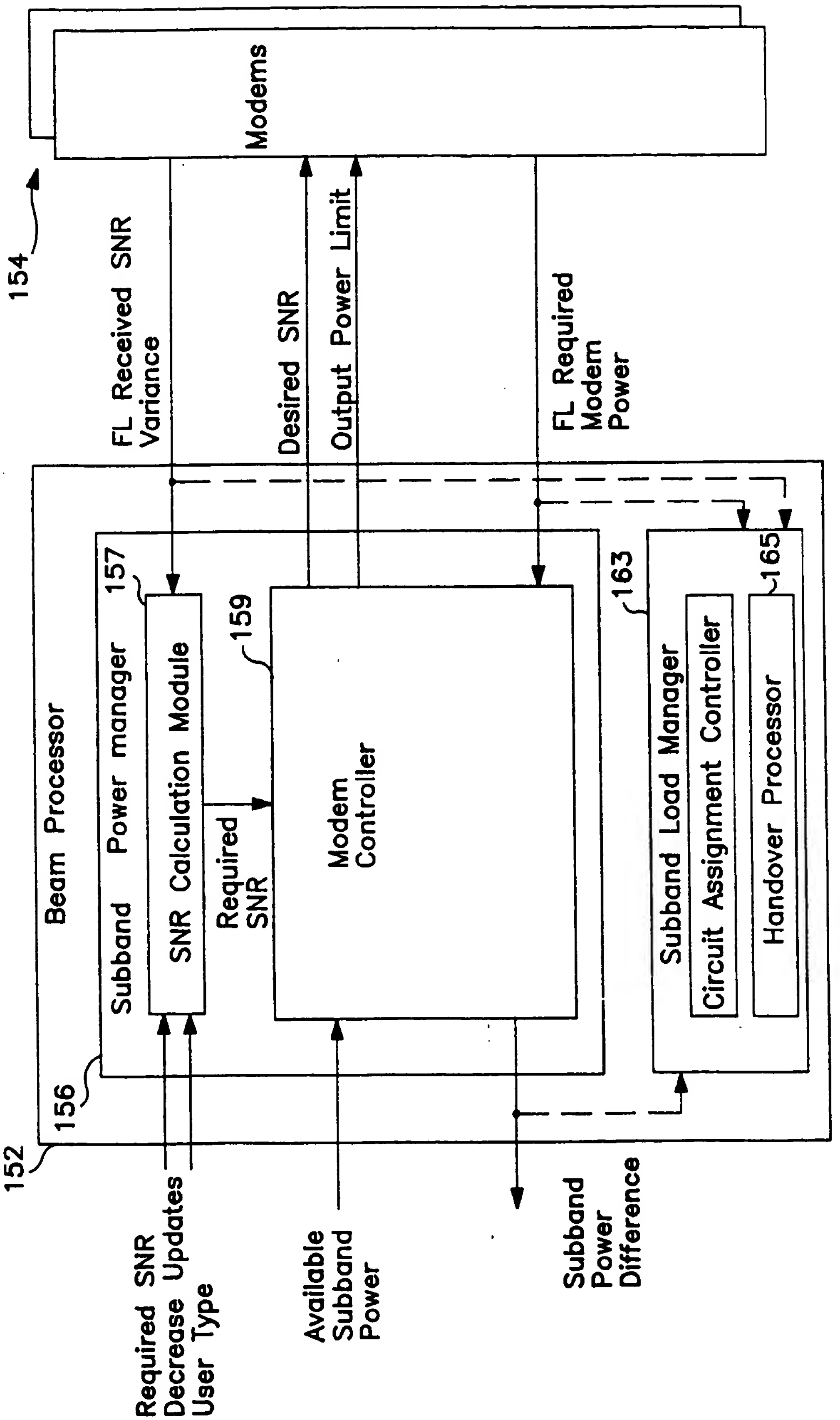

Modems
154
FL Received SNR
Variance
Desired SNR
Output Power Limit
FL Required
Modem
Power
152
Beam Processor
156
Subband Power manager
157
SNR Calculation Module
Required
SNR
159
Modem
Controller
163
Subband Load Manager
Circuit Assignment Controller
165
Handover Processor
Required SNR
Decrease Updates
User Type
Available
Subband
Power
Subband
Power
Difference

FIG. 4

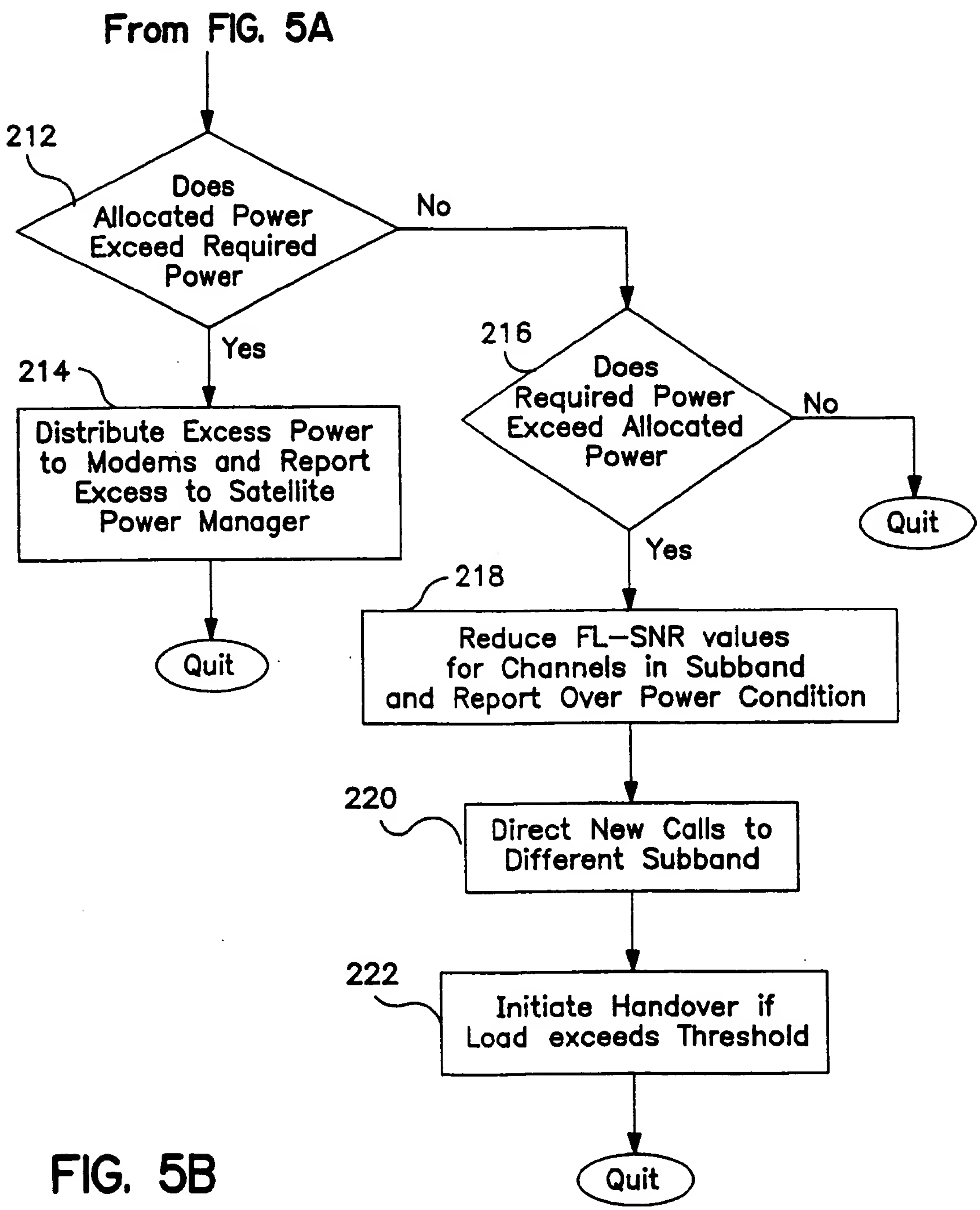
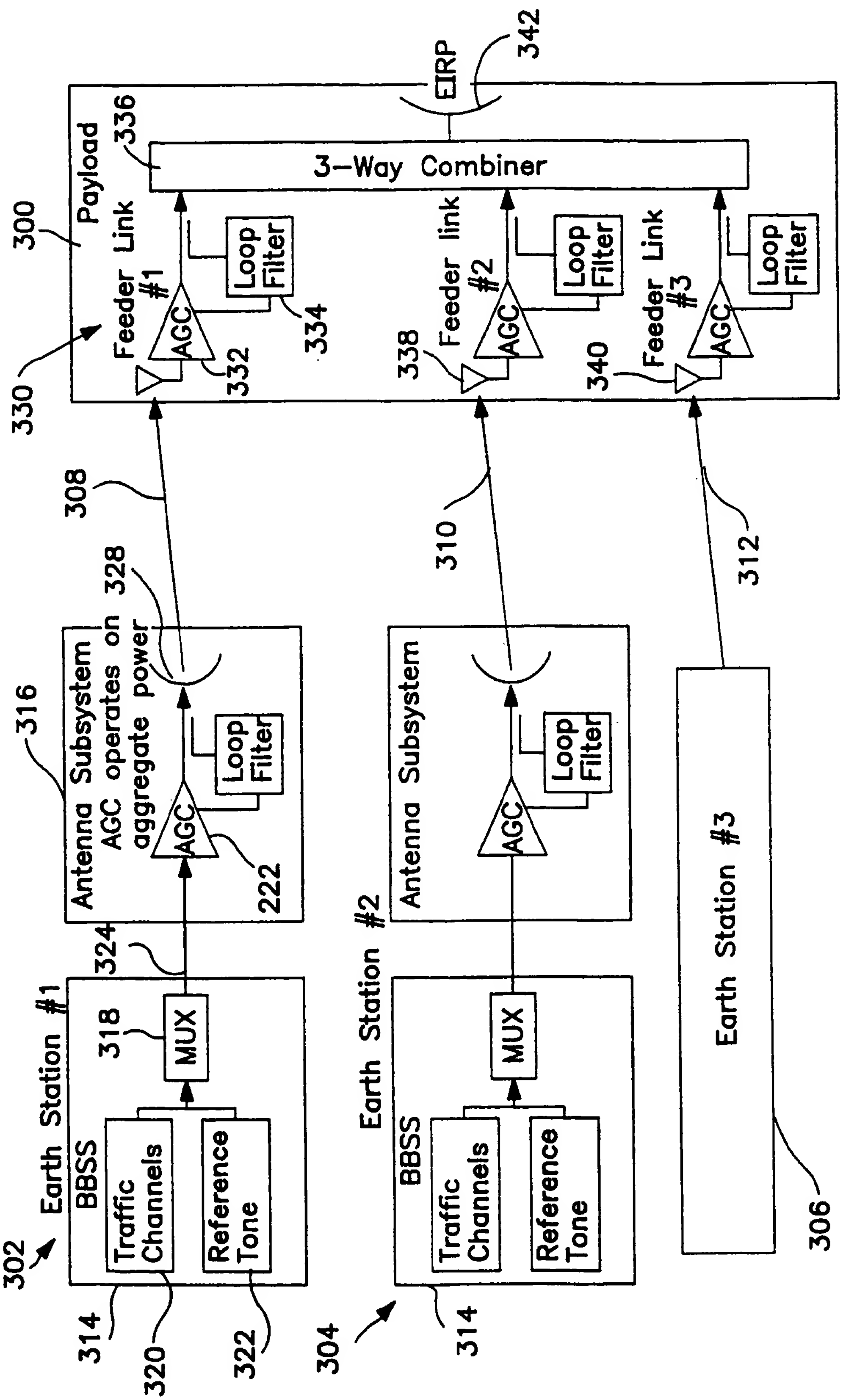

From FIG. 5A
212
Does Allocated Power Exceed Required Power
No
Yes
214
Distribute Excess Power to Modems and Report Excess to Satellite Power Manager
Quit
216
Does Required Power Exceed Allocated Power
No
Quit
Yes
218
Reduce FL—SNR values for Channels in Subband and Report Over Power Condition
220
Direct New Calls to Different Subband
222
Initiate Handover if Load exceeds Threshold
Quit

FIG. 5B



Payload
300
330
3-Way Combiner
336
EIRP
342
Feeder Link #1
AGC
332
Loop Filter
334
Feeder link #2
338
AGC
Loop Filter
Feeder Link #3
340
AGC
Loop Filter
308
310
312
Antenna Subsystem
AGC operates on aggregate power
316
328
AGC
222
Loop Filter
Antenna Subsystem
AGC
Loop Filter
Earth Station #1
302
BBSS
Traffic Channels
Reference Tone
MUX
318
324
314
320
322
Earth Station #2
304
BBSS
Traffic Channels
Reference Tone
MUX
314
Earth Station #3
306

FIG. 8

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 10 6564

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 275 118 A (NIPPON ELECTRIC CO) 20 July 1988 * abstract; claim 1; figures 5-7 * * column 10, line 47 - column 15, line 45 *	1	H04B7/185 H04B7/005
A	US 4 261 054 A (SCHARLA-NIELSEN HANS) 7 April 1981 * abstract; figure 1 *	1	
A	US 5 446 756 A (MALLINCKRODT ALBERT J) 29 August 1995 * abstract *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	23 June 1997	Kolbe, W

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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